Lesson 28: Mass, Weight, & Fields

Newton's work was all related to one goal he had for himself... to explain gravity.

- Newton realized that to explain the force due to gravity, he would first have to come up with a set of rules to explain forces in general. That's the stuff we've been working on in the last few lessons.
- Newton stated that a gravitational force exists between any two masses.
  - According to his Third Law, this means that when you fall the Earth is pulling you down, while you are pulling the Earth with just as much force up.
  - We don't see the Earth move because it has so much more mass than you that the Earth's inertia (tendency to keep doing what it is already doing) is enormous.

Weight vs Mass

Normally when a person wants to know his or her mass, they will just stand on a scale.

- Since this depends on the **force due to gravity** pulling you down, you are actually measuring your **weight**, a force acting on your body.

$$\textbf{Weight} = F_g = mg$$

- Your **weight** is measured in **Newtons** (just like any other force) and is different in different locations on Earth (since "g" varies from place to place).

Mass is considered to a be constant anywhere in the universe.

- Floating in space, you could hold a car in your hand… it's easy because it has no **weight**.
- Throw it at someone and it hits them with its inertia… it hurts!
  - This is because it still has **mass**, so it will tend to keep doing what it is already doing.
- The amount of material that makes up the car is the same in space as it is on Earth, so they have the same **mass**.
- The **mass** of an object is like asking "how many atoms are in that object?"… this number will always be the same, no matter where you are in the universe.
- **Mass** is always measured in **kilograms.**

Some textbooks make a distinction between **gravitational** mass and **inertial** mass. They are both still a measurement of mass in kilograms. The only difference is really just how it is measured. Gravitational mass is measured by comparing a known mass to an unknown mass. Inertial mass is measured by seeing how much the mass accelerates when a force is applied to it.

The best way to determine the mass of an object is to apply a known force to it and measure its acceleration.

- This is known as the **inertial mass**, since it depends on the inertia of the object.
- Changes in the local acceleration due to gravity would not change this measurement.

Example 1: I have a 5.00kg rock.

a) **Determine** how much it weighs on the Earth and on the Moon.

b) **Determine** its **mass** on the Earth and on the Moon.

a) Weight is measured in Newtons!

On Earth...

$F_g = mg = 5.00\text{kg}\ (9.81\text{m/s}^2) = 49.1\text{N}$

On the Moon...
$F_g = mg = 5.00kg\ (1.67 m/s^2) = 8.35N$

b) The mass of the object on the Earth and the moon is 5.00kg! The object has the same matter making it up even if I take it to a different place.

Example 2: An object is accelerated at $3.24 m/s^2$ by a 68.0 N force. **Determine** its inertial mass.

$$F = ma$$

$$m = \frac{F}{a} = \frac{68.0}{3.24} = 20.98765 = 21.0 kg$$

Gravitational Fields

> DID YOU KNOW?
> The idea of "fields" is also used in Social Studies classes. The difference is that they call it a "Sphere of Influence." For example, the former USSR had a sphere of influence that extended outwards to many nations that were nearby.

Newton realized that the gravity that keeps you on the Earth is the same gravity that keeps the moon in its orbit around the Earth.

- To explain this **action-at-a-distance** force, physicists often use the idea of **fields**.
- A **field** is an area around an object that has an effect on nearby objects.
- In the case of **gravitational fields**, the field always points in towards the centre of the mass.
- All masses have a **gravitational field**, but only the **gravitational fields** of large objects (like planets) are easily noticeable.

To measure and show the gravitational field around an object, we would place a known **test mass** nearby.

- The test mass is any mass we choose, as long as it is small enough that it does not have a significant gravitational field of its own (theoretically its mass should be $\frac{1}{\infty} kg$, which is so close to zero that it doesn't even really matter).
- The test mass will always move towards the centre of the object, so we draw vectors pointing in towards the centre.
- By measuring the force of gravity pulling the test mass towards the object, we have a measurement of the **gravitational field** near the object.

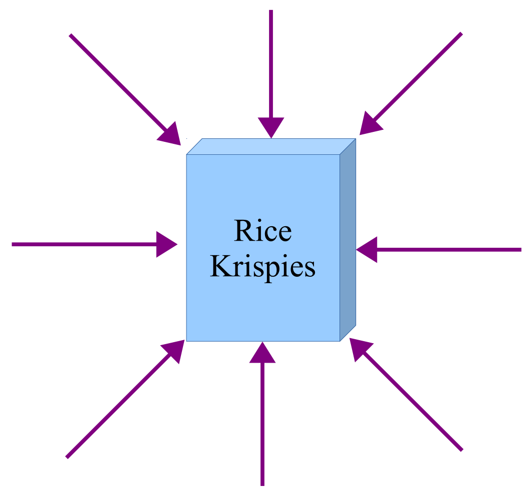


Illustration 1: Although weak, there is a gravitational field around a cereal box.

$$g = \frac{F_g}{m}$$

You'll notice that we are actually measuring the acceleration due to gravity at that location.

- We could certainly measure it in m/s^2, or we can choose to use units that have more to do with the experiment we just did, N/kg .
- On many data sheets you'll see that the acceleration due to gravity is also listed as a gravitational field strength.

- You'll probably see the value listed near Earth's surface as 9.81 **m/s^2** and 9.81 **N/kg**. The two ideas are used pretty interchangeably in most questions.

It is also reasonable to say that the effect of gravity is greatest when closer to the object.

- As you move further and further away from the centre, the force exerted by gravity becomes weaker (although it never truly disappears).
- Illustration 1 shows this by the way the vectors are further apart from each other when more distant from the object. Closer in the vectors are closer to each other.
  - This means the **gravitational field** is stronger when gravitational field vectors are drawn closer.
- As a relationship, this is shown by...

$$g \alpha = \frac{1}{r^2}$$

- This inverse square relationship became the basis of one of Newton's greatest formulas, the ***Law of Universal Gravitation***.

Homework

p202 #1,2,4,5,7,9

Lesson 30: Gravitational Field Strength

In the last lesson we were able to combine our two formulas for force due to gravity to get a new formula.

$$F_g = F_g$$
$$m_{test}\, g = \frac{G m_{test} M_e}{r^2}$$
$$g = \frac{G M_e}{r^2}$$

- The great news is that the mass (shown above as the mass of the Earth "M_e") can actually be any mass. It could be the mass of the moon, Mars, an asteroid, whatever!
- In fact, we should replace ***mass of the Earth*** in the formula with just ***mass***, since it can be any mass.

$$g = \frac{G m}{r^2}$$

g = gravitational field strength (m/s^2)
G = Universal Gravitational Constant
m = mass of object producing the field (kg)
r = distance from centre of mass (m)

- This formula lets you calculate the the gravitational field strength (the acceleration due to gravity) caused by that mass ata specific distance from its centre.

Example 1: The planet Mars has a mass of 6.42e23 kg and a radius (from its centre to the surface) of 3.38e6 m.

a) **Determine** how much a 60.0 kg person would weigh on Mars.
b) **Compare** it to his weight on Earth.
c) **Determine** how heavy the 60.0 kg person would "feel" as an **apparent** mass in kilograms on Mars.

a) To determine someone's weight, we first need to know the acceleration due to gravity on Mars.

$$g = \frac{G m}{r^2}$$
$$g = \frac{6.67\text{e-}11(6.42\text{e}23)}{(3.38\text{e}6)^2}$$
$$g = 3.748240608 = 3.75\, m/s^2$$

So the person's weight will be...

$$F_g = mg$$
$$F_g = 60.0(3.748240608)$$
$$F_g = 224.8944365 = 225\,N$$

b) On Earth the person has a weight of…

$$F_g = mg$$
$$F_g = 60.0(9.81)$$
$$F_g = 588.6 = 589\,N$$

Probably the easiest way to compare the person's weight on Mars and the Earth is to find the ratio of the two.

$$\frac{F_{gearth}}{F_{gMars}} = \frac{589}{225} = 2.6172279 = 2.62$$

Since this is a ratio, it has no units (the Newtons canceled each other out). It simply means that you weigh 2.62 times more on the Earth as compared to Mars.

c) The reason I asked for the person's **apparent** mass is because I want to know how heavy the person thinks he feels in kilograms. In reality, **the true mass of a person never changes**. I am asking how heavy he feels based on the facts that he *feels* lighter on Mars, and that they are used to the effects of gravity on Earth. We will take the person's weight on Mars and the gravity of Earth to find out the apparent mass.

$$F_g = mg$$
$$m = \frac{F_g}{g}$$
$$m = \frac{224.8944365}{9.81}$$
$$m = 22.925019 = 22.9\,kg$$

Keep in mind that the person's mass is still really 60.0 kg. He just feels like he is only 22.9 kg because he is on Mars.

The Elevator Question

The concept of gravity becomes a bit more complicated when you examine a complex system like an elevator going up and down.

- It might sound strange to call an elevator complex, but it really does make a challenging problem.
- How do you think you would solve a question that asks you about your weight as an elevator accelerates up or down?

Going up...

When the elevator is accelerating up, what would happen to your weight?

- Have you ever noticed that when an elevator first starts to move up, you feel as though you are being pushed down a little?
  - This is because you can feel the elevator's acceleration. The elevator is pushing you up, so (according to Newton's Third Law) you push down against the floor.
- It basically makes you feel a bit heavier for a moment.
  - A scale would show this as an increase in your weight (temporarily). If the scale shows kilograms, it would show your **apparent** mass as being bigger than your true mass.

Going down...

What would happen to your weight if the elevator started to accelerate down?

- You would feel the elevator drop out underneath you.
  - If it really dropped out underneath you, it would feel just like being on the "Space Shot " at Galaxyland as it is falling … you'd feel weightless!
- You feel this way because as the elevator accelerates down (away from you) it is not pushing up against you as hard as it was before. Since the floor is not pushing as hard up against you, you are not pushing as hard down against the floor (Newton's Third Law again).
  - A scale would show your weight as being less. If the scale shows kilograms, it would show your **apparent** mass as being smaller than your true mass.

Let's look at how we would actually figure out some numbers for this type of question by looking at an example.

- Keep the following in the back of your mind. A regular scale that you buy in a regular store is made to measure things in kilograms, and it is built for Earth's regular gravity of $9.81 m/s^2$. You'll see why this is important later.

Example 2: You are standing on a scale in an elevator. You have a mass of 75kg. Determine what a scale would show as your **apparent** mass (in kilograms) if…

a) the elevator starts to accelerate upwards at $3.0 m/s^2$.

We have three parts in the formula that we will have to use:

F_{NET} = the overall force acting on the person causing acceleration upwards.

F_g = the force due to gravity pulling the person down.

F_N = the force of the scale on the floor pushing up against the person.

We should mostly be concerned with what the normal force is, since however hard the scale has to push the person upwards will show up as a reading on the scale. We know the force due to gravity, since that's just the person's weight. The net force is just overall what is happening to the person.

$$F_{NET}=F_g+F_N$$
$$ma=mg+F_N$$
$$ma-mg=F_N$$
$$m(a-g)=F_N$$
$$75[3.0-(-9.81)]=F_N$$
$$75[12.81]=F_N$$
$$F_N=960.75$$
$$F_N=9.6e2\,N$$

We start off with a standard net force formula. We do a quick substitution, since F_{NET} = ma and F_g = mg. Next step is to move "mg" to the other side. Since both formulas on the left side have "m" we can factor it out. Now start putting in the numbers, watching out for the directions of the accelerations. This lets us calculate the normal force. As hard as the scale is pushing the person up, the person must be pushing down just as hard which tells us the weight the scale will show in Newtons.

The question asked about the **apparent** mass, not the weight of the person.

- I can change this into a reading in kilograms by remembering that the scale we're using has no idea what is going on... it was originally calibrated to be sitting in someone's bathroom where gravity is a nice constant 9.81m/s^2.
- This is ***not*** the true mass of the person, since mass never really changes.

$$F_N = mg$$
$$m = \frac{F_N}{g}$$
$$m = \frac{960.75}{9.81}$$
$$m = 97.93577982 = 98\,kg$$

So a regular scale shows an **apparent** mass of 98 kg!

b) the elevator starts to accelerate downwards at 4.0m/s^2.

We'll handle this part of the question the same way.

$$F_{NET} = F_g + F_N$$
$$ma = mg + F_N$$
$$ma - mg = F_N$$
$$m(a-g) = F_N$$
$$75[-4.0-(-9.81)] = F_N$$
$$75[5.81] = F_N$$
$$F_N = 435.75 = 4.4e2\,N$$

Since the scale is pushing up against the person with 4.4e2 N of force (the weight that shows on the scale in Newtons), the person's apparent mass will be...

$$F_N = mg$$
$$m = \frac{F_N}{g}$$
$$m = \frac{435.75}{9.81}$$
$$m = 44.418960 = 44\,kg$$

So a regular scale shows your apparent mass as 44 kg.

Homework

p.219 #1-3
p.225 #1
p.231 #1, 3-6, 8, 9

Lesson 6: History & Theories of Static Electricity

Ancient Times

If you ask people who discovered electricity, they'll probably tell you names like Benjamin Franklin (*flying his kite during a lightning storm*), Thomas Edison (*invents the light bulb*), or Alessandro Volta (*makes the first batteries*). did.

- These are **NOT** the people who discovered electricity!
  - Electricity was first mentioned in the works of a Greek scientist named Thales of Miletus in about 600BC!
    - Thales noticed that if amber (hardened tree sap) was rubbed, it had the ability to pick up dust and leaves
    - What he was seeing is what we now call "static electricity"
  - Another Greek named Theophrastus noticed in 300BC that other substances had static electricity if rubbed.
  - Unfortunately neither Thales nor Theophrastus had any scientific explanation for it… they just thought it was interesting.

Illustration 1: Amber pendants (photographed by Adrian Ringstone)

What they did realize was that sometimes two objects would attract each other, sometimes they would repel.

- This developed into the idea that there are two kinds of charge (we call them positive and negative today, which will be discussed shortly).
  - Like charges repel
  - Opposite charges attract.
- This is usually called the **Law of Charges**.

Middle Ages

In 1600AD an Englishman named William Gilbert started studying these phenomena.

- He wanted to come up with a good scientific explanation for these ancient discoveries.
- He was actually the first person to use the word "electric," which is a variation of the Greek name for amber.
- Although he had only some success in describing electricity, he was able to show that there were differences between magnetism and electricity that seemed to indicate that they were completely different things.
  - For example, an amber rod had to be rubbed to have electric effects; a magnet was always a magnet (didn't need to be rubbed).
- Up until that point most scientists had believed electricity and magnetism were just different versions of the same thing.

> DID YOU KNOW?
> William Gilbert was the Court Physician to both Queen Elizabeth I and King James I. This meant that he acted as an adviser in scientific matters

The “Franklin” Era

Benjamin Franklin’s Experiments

Benjamin Franklin (1706-1790) started his investigations after Gilbert.

- Yes, he did fly a kite on an overcast day (no actual lightning), but he wasn’t the first person to do it!
  - Several people had tried to do it before him to prove that lightning was electrical, but they’d all been killed.
  - Most people thought he was a nut to do it. In fact, he had his son set up most of the equipment while he stood back.
  - Franklin was able to prove that lightning was a discharge of static electricity (this does **NOT** mean he discovered electricity!!!)

Most of Franklin’s research actually focused on amber rods…

- It had been found that if a rubbed **amber** rod was dangling from a string, and another rubbed **amber** rod was brought near, the dangling one would move away.
- If a dangling rubbed **glass** rod is brought near another rubbed **glass** rod, the dangling one would move away.
- If a rubbed **glass** rod and **amber** rod were brought near to each other, they were attracted.
- Therefore, the charge on the **glass** must be different from the charge on the **amber**!

Franklin decided to say that…

- the **glass** rod had a **positive** charge
- the **amber** rod (or the plastic **ebonite** used today) had a **negative** charge

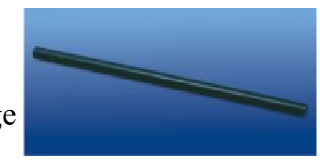


Illustration 2: Ebonite is a type of plastic often used in physics because it can easily build up a static charge.

Why did he choose to call **glass positive** and **amber negative**?

- No reason! He knew they were different and opposite to each other, so he just picked one to be **positive** and the other **negative.**

Franklin’s Single Fluid Theory

Franklin developed what he called a “***single-fluid***” theory to explain the results he was getting.

- According to this theory, all matter contains an “***electric fluid***”, a substance that Franklin thought all matter in the universe had. His ***electric fluid*** had a ***positive charge***.
  - An object with a positive charge has an excess (too much) of this positive electric fluid.
  - An object with a negative charge has a deficiency (too little) of of this positive electric fluid.

Franklin backed up his theory with the observation that if a certain amount of charge is produced in one object, an equal amount of *opposite* charge is produced on another object.

- For example, lets say you rub a balloon on your head. The balloon will gain just as much **negative** charge as your hair will gain **positive** charge.
  - According to this model, the electric fluid flows from one object to the other.
- Franklin used the idea of **negative** and **positive** to figure out algebra problems, since if you charged anything, the two objects’ charges would add up to zero.
  - This would be like if you rub a plastic ruler with a paper towel. The ruler has a **negative** charge, and the paper towel and equal **positive** charge. The charges are separate from each other, but add up to zero.

Modern Theories

Although Franklin's single fluid theory is not exactly right, it did lead him to a law that we still use today in physics…

Law of Conservation of Charge

The net amount of electric charge produced in any process is zero

This just means that even though you can move around charges, you can't create or destroy them.

Example 1: You have two similar objects; one of them has a charge of +7, and the other has a charge of -3. They touch, share their charges, and then are moved apart. Determine the final charge of each of the objects.

When the two objects touch, their charges will redistribute. We need to add them algebraically, and then figure out what the charge on each is.

$+7 + -3 = +4$ <<< This is the total net charge between the two objects.

$+4 / 2 = +2$ <<< Since the charge is shared between the two objects, each is +2.

The net charge at the start was +4, and the net charge afterwards was still +4.

In the past 100 years it has become clear that these charges depend on the makeup of the atom itself, not on some "fluid"

- The nucleus is made up of **protons** (**positive**) and **neutrons** (**neutral**), surrounded by **electrons** (**negative**) in orbit.
- In a "normal" state the **electrons** and **protons** balance out, so the charge is **neutral**.

Sometimes the atom may lose or gain **electrons**.

- Nothing happens to the stable nucleus made up of **protons** and **neutrons**.
- It is the **electrons** that are being stripped off or added on because they are on the far outside edge of the atom.
- If the atom loses electrons it will have a **positive** charge… if it gains electrons it has a **negative** charge.
- Either way, it is now called an ***ion***.

Usually when an object is charged by rubbing, the charge only lasts a little while… where does the charge go?

- Most of the charge "leaks off" to water molecules in the air
  - Remember, water is a polar molecule, which means one end is more **negative** and the other is more **positive**.
  - The **positive** end can temporarily pick up **electrons**.
- This is why there is more static electricity in the winter.
  - The air is more dry, so the electrons aren't picked up as often.

Homework

p.523 #2, 3

Lesson 9: Coulomb's Law

Charles Augustin de Coulomb

Illustration 1: Charles Coulomb

Before getting into all the hardcore physics that surrounds him, it’s a good idea to understand a little about Coulomb.

- He was born in 1736 in Angoulême, France.
- He received the majority of his higher education at the Ecole du Genie at Mezieres (a french military university with a very high reputation, similar to universities like Oxford, Harvard, etc.) from which he graduated in 1761.
- He then spent some time serving as a military engineer in the West Indies and other French outposts, until 1781 when he was permanently stationed in Paris and was able to devote more time to scientific research.

Between 1785-91 he published seven memoirs (papers) on physics.

- One of them, published in 1785, discussed the **inverse square law** of forces between two charged particles. This just means that as you move charges apart, the force between them starts to decrease faster and faster (exponentially).
- In a later memoir he showed that the force is also proportional to the product of the charges, a relationship now called “**Coulomb’s Law**”.
- For his work, the unit of electrical charge is named after him. This is interesting in that Coulomb was one of the first people to help create the metric system.
- He died in 1806.

The Torsion Balance

When Coulomb was doing his original experiments he decided to use a **torsion balance** to measure the forces between charges.

- You already learned about a torsion balance in Physics 20 when you discussed Henry Cavendish’s experiment to measure the value of “G” , the universal gravitational constant.
  - Review Cavendish’s work in the Physics 20 notes (Chapter 4 Lesson 29: Newton's Law of Universal Law of Gravitation) if you need to.
- Coulomb was actually doing his experiments about 10 years ***before*** Cavendish.
- He set up his apparatus as shown in Illustration 2 with all spheres charged to have the same sign.
  - He charged one of the free moving spheres by touching it to an already charged object (charging by conduction).
  - He then touched that one sphere to the other free moving sphere (charging *it* by conduction).
  - Each of the free moving spheres was then touched to one of the spheres on the rod (guess what... charging by conduction!).

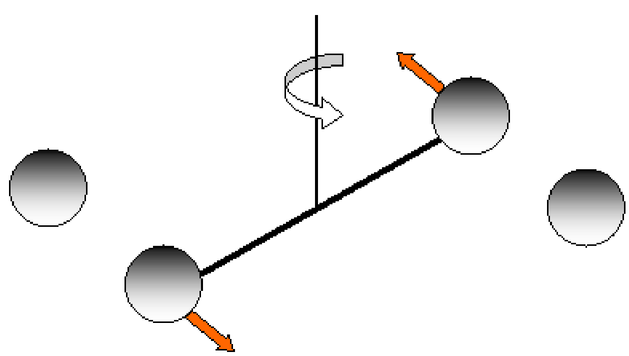


Illustration 2: The Torsion Balance

- Although he didn't know the actual charge on any particular sphere, Coulomb did know that each sphere had an equal charge to all the rest.
    - Coulomb also altered the experiment by using spheres of different sizes so he could get the amounts of charge in different ratios, and by touching spheres to other objects to get other ratios of charges.

Because like charges repel, the spheres on the rod twist away from the other spheres.
- By knowing the distance between the spheres, the force needed to twist them (the torque in the string holding up the rod, from which the torsion balance gets it name), and the charges on the spheres, he could figure out a formula.

In the end, the formula Coulomb finally came up with could be used to calculate the force between any two charges separated by a distance…

$$|F_e| = \frac{k q_1 q_2}{r^2}$$

F_e = Force (N)
q = Charge (C)
r = distance between the charges (m)
k = 8.99e9 Nm^2/C^2

- We will calculate the **absolute value** of F_e to get just the **magnitude** of the force.
- Then, we can use information about the charge on the objects to figure out if they are attracting or repelling, and from that we can figure out which direction the force is acting.
    - For example, if both the charges are positive, then we know that they will repel each other by pushing away in opposites directions.
- The reason we need to be so careful with this is that you are used to forces having positive and negative values because **force** is a **vector** with directions like negative meaning "to the left."
    - We are now dealing with a formula where the positive and negative signs come from the **charges**, which are **scalar**.

Special AP Physics Note
In Coulomb's law "k" is sometimes shown as being equal to another set of variables...

$$k = \frac{1}{4\pi\epsilon_o}$$

The symbol ε_o ("epsilon") is a constant known as the vacuum permittivity (aka the permittivity of free space), where ε_o = 8.85e-12 $C^2/N\cdot m^2$

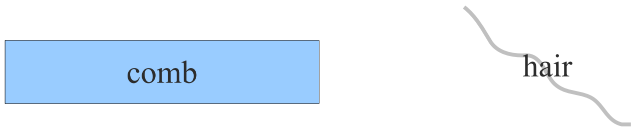
Example 1: A comb with -2.0 μC of charge is 0.15m to the left from a hair with 3.0 μC of charge. **Determine** the force the hair exerts on the comb.

$$F_e = \frac{k q_1 q_2}{r^2}$$

$$F_e = \frac{8.99e9 \, x \, 2.0e\text{-}6 \, x \, 3.0e\text{-}6}{0.15^2}$$

$$F_e = 2.397333 = 2.4\,N$$

That's enough force to probably make the hair jump towards the comb. Notice that I did not put in the negative sign on the charge of the hair. Now that we know the magnitude of the force, we can decide how that force is acting on the comb.



- Since the comb is negative and the hair is positive, they will attract each other.
- That just means the comb and hair are pulling each other closer together.
- If they are pulling closer together, then the comb is being pulled to the right, and the hair is being pulled to the left (in the diagram shown above).
- We only care about the comb, so we can just say that the force is **2.4 N [right]**.
- Notice that if you had put the negative sign in the formula, your answer would have been negative, and you may have incorrectly said the force was to the left.

You might have noticed the charges used in the last example were micro Coulombs.

- In most lab work you would do at school, or even just in everyday life, charges are usually in this range of about 10^{-6}C (1 μC).
- Only really special cases have charge of 1 C or 2 C... things like a lightning bolt!
- Common subatomic particles can have a charge, as shown in the following table.

Particle	***Charge***
Electron (e^-)	- 1.60e-19 C
Proton (p^+)	+1.60e-19 C
Neutron (n^0)	0 C

- A charge of 1.60e-19 is so important, that it is called an **elementary charge**, and its symbol is just the letter "**e**".
  - This is not "e" for electron, since there is no negative sign on the symbol.
  - If it was written as e^- with the little minus sign on it, then it would refer to an electron.
  - You will find the value of the elementary charge on your data sheet.
- That means that if something has a charge of -1 C, it has a LOT of electrons...

$$1\,C\,x\,\frac{1\,electron}{1.60\text{e-}19\,C}=6.25\text{e}18\,electrons$$

- Although day to day objects can have this (or more!) electrons, keep in mind that they will often have an equal number of protons to cancel out the charges, for a net charge of zero.

Comparing Electrostatic Force to Gravitational Force

You might have noticed that Coulomb's Law looks almost identical to the formula for Universal Gravitation…

$$F_g=\frac{G\,m_1 m_2}{r^2}$$

- Both formulas calculate a force by multiplying a constant by a measured value of the two objects, divided by the square of the distance separating them.
  There is one significant difference between the two forces.
  - **The gravitational constant G is very small**.
  - **The electrostatic constant k is huge**.

Both of these formulas are examples of “inverse square laws,” formulas where as the distance (r) increases, the measured value exponentially decreases.

- Because of this difference, **gravitational forces are very weak**, while **electrostatic forces are very strong**.
  - You might disagree with this, thinking about how gravity seems so strong while keeping you stuck to the Earth right now.
  - Think of it this way. When you use a rubbed ebonite rod to attract some bits of paper and lift them up, you are using a whimpy little charged rod's electrostatic force to beat the entire gravitational force of the whole planet Earth pulling down.

- Another important difference is that **gravitational force** can only cause **attraction**, but **electrostatic force** can cause **attraction** *or* **repulsion**.

Multiple Charges in One Dimension (Linear)

Things get a bit more interesting when you start to consider questions that have more than two charges.

- You will almost always deal with three charges in these linear problems.
- In the following example you have three charges lined up and are asked to calculate the net force acting on one of them.
- Do one step at a time, and then combine the answers at the end.

Example 2: The following three charges are arranged as shown. **Determine** the net force acting on the charge on the far right (q_3).

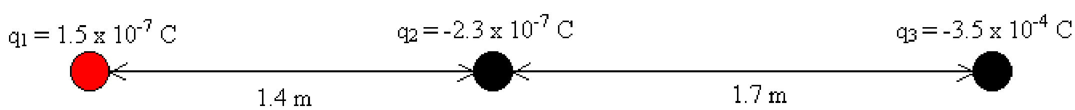


Illustration 3: Arrangement of charges in Example 2

Calculate the force between one pair of charges, then the next pair of charges, and so on until you have calculated all the possible combinations for that particular question. Remember, if you've calculated the force of q_1 on q_2, then you also know the force of q_2 on q_1 ... they're the same!

Step 1: Calculate the force that charge 1 exerts on charge 3...

It does **NOT** matter that there is another charge in between these two… ignore it! It will not effect the calculations that we are doing for these two. Notice that the **total** distance between q_1 and q_3 is 3.1 m , since we need to add 1.4 m and 1.7 m .

$$F_e=\frac{k\,q_1 q_3}{r^2}=\frac{8.99e9(1.5e\text{-}7)(3.5e\text{-}4)}{3.1^2}=0.049112903\,N$$

Since q_1 is positive and q_3 is negative, there will be a force of attraction between them. We know that q_1 is pulling charge q_3 left, while charge q_3 is pulling q_1 to the right. Since all we care about is what is happening to q_3, all I really need to know from this is that q_3 feels a pull towards the left of 0.049112903 N.

Step 2: Calculate the force that charge 2 exerts on charge 3...

Same thing as above, only now we are dealing with two negative charges, so the force will be repulsive.

$$F_e = \frac{k\,q_2 q_3}{r^2} = \frac{8.99e9(2.3e\text{-}7)(3.5e\text{-}4)}{1.7^2} = 0.250413495\,N$$

Since we know that the force is repulsive between these two charges, q_2 is pushing q_3 to the right with a force of 0.250413495 N. Again, we only care about what is happening to q_3.

Step 3: Add you values to find the net force.

- We now need to add the two values from above, being careful about directions. Everything has to be based on the directions of the forces acting on q_3... we don't care about the other charges anymore.
  - The 4.9e-2 N force is pulling q_3 to the left, which is the direction we usually call negative, so we'll put the negative sign on it. **F_e = - 0.049112903 N.**
  - We also have a 2.5e-1 N force pushing to the right. We usually call a vector pointing right positive, so we'll do that here also. **F_e = + 0.250413495 N**

F_{NET} = - 0.049112903 N + +0.250413495 N = 0.201300592 = 0.20 N

- Since the answer is positive, we know that the net force acting on q_3 is **0.20 N [right]**.

Multiple Charges in 2 Dimensions

Doing questions with charges in multiple dimensions are the same as the question you did above. You just need to be careful about directions and use vectors to figure out the problem.

- Figure out all the individual forces between pairs of charges (just like in the 1-D problem).
- Then pay attention to the directions of the forces and calculate the net force as you would any vector problem.
  - This will usually (but not necessarily always) involve a triangle diagram.

Example 3: Three charges are arranged in a right angle triangle as the following diagram shows. **Determine** the force on q_2 .

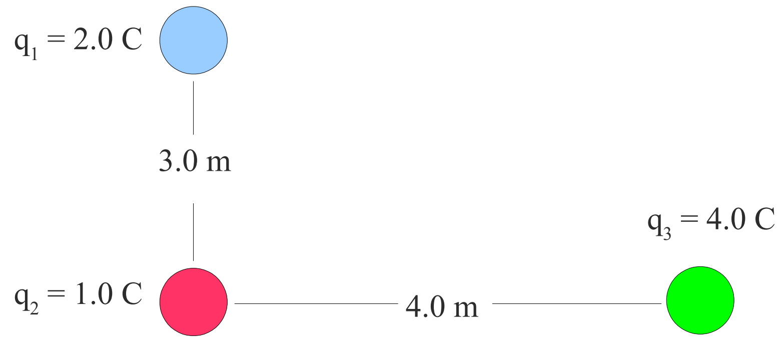


Illustration 4: Arrangement of charges for Example 3

We need to start by calculating the individual forces on q_2 by each of the other charges. These must be calculated individually.

$${}_1F_2 = \frac{k\,q_1 q_2}{r^2} = \frac{8.99e9\,x\,2.0\,x\,1.0}{3.0^2} = 1\,997\,777\,777\,N$$

$${}_2F_3 = \frac{k\,q_2 q_3}{r^2} = \frac{8.99e9\,x\,1.0\,x\,4.0}{4.0^2} = 2\,247\,500\,000\,N$$

All of the charges are positive, so all of the forces are repulsive. That means that ${}_1F_2$ is a force that is pushing q_2 down, and ${}_2F_3$ is a force pushing q_2 to the left.

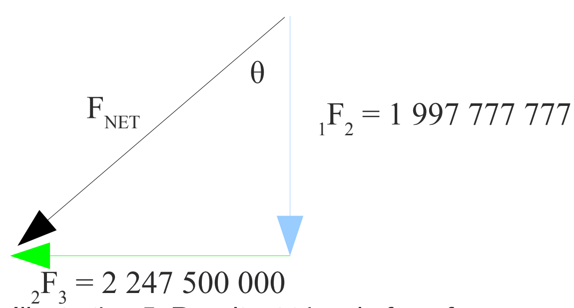


Illustration 5: Resultant triangle from forces acting on the charge.

It's easy enough to calculate F_{NET} using Pythagoras, and figure out the angle using trig.

$c^2 = a^2 + b^2$
$\quad = (1\,997\,777\,777)^2 + (2\,247\,500\,000)^2$
$c = 3\,007\,053\,757 = 3.0e9$ N

$$\tan\theta = \frac{opp}{adj}$$

$$\tan\theta = \frac{2247500000}{1997777777}$$

$$\theta = 48.36646 = 48^{O}$$

The final answer is that q_2 feels a net force of 3.0e9 N at an angle 48^0 clockwise from a vertical line pointing down. Including a diagram with your answer is a great way to show what your direction means.

Homework

1D Questions
p530 #1
p531 #1
p532 #1
p533 #1

2D Question
p534 #2
p535 #1

Review
p540 #5, 6, 12, 17, 23, 25, 26

Lesson 10: Electric Fields

Just like the force due to gravity, the force due to electric charges can act over great distances.

- Keep in mind that most forces we deal with in everyday life are ***not*** like this.
  - We mostly deal with "**contact forces**"… objects touch each other directly in order to exert a force on each other.
  - For example, a tennis racket hits a tennis ball
- The idea of even considering forces that could happen without anything touching ("**action at a distance**") was very difficult for early scientists to accept, from Aristotle to Newton.
  - It is necessary though, if you are going to be able to explain a falling ball, or two positive charges pushing away from each other.

The British scientist Michael Faraday came up with the idea of a **field** and applied it to the study of electrostatics.

Illustration 1: Michael Faraday

- A **field** is sometimes defined as a sphere of influence. An object within the **field** will be affected by it.
  - Think of how you talk about countries in social studies... large, powerful nations can have an influence on nearby countries. Usually as you get further away from the powerful nation, the influence they have on other countries decreases.
  - Or think about being near your gym bag after playing a soccer game. Sitting right next to it the stink is pretty intense (yuck!), but as you move away the smell isn't quite so bad.

There are two kinds of fields...

1. **Scalar Fields**: magnitude but no direction

   Example 1: Heat field from a fire: If you stand by a campfire, you can measure the magnitude (temperature) of the field with a thermometer; if you are close to the fire you will measure a stronger field (higher temperature), but if you move away the field strength decreases (lower temperature). You would **not** be saying anything about a direction, like "25^{o}C South".

2. **Vector Fields**: magnitude and direction

   Example 2: A gravity field is a measure of the Newtons exerted per kilogram of mass *towards the centre* of another mass.

Electric fields are vector fields that exist around any charge (positive or negative).

- If one charge is placed near a second charge, the two fields will "touch" and exert a force on each other.
  - Note: the field is ***NOT*** a force, but it does exert a force! It's just like if you watch a person pushing a box; we don't say the person *is* a force, just that he is *exerting* a force.
- This meant that physicists had a mathematical way of showing how a force could be transferred over a distance without anything actually touching.
  - This model is not considered to be complete, but it is good enough for the way we need to look at things for the time being.

How can we detect and measure the electric field around a charge?

- The easiest way is to place another known charge near by and see how it reacts.
- We do need to be careful since both the charges have their own fields that will interact with each other, so that would affect your results.
  - Physicists have defined something called a **test charge** as the mathematically perfect charge that could be brought near another charge (the **source charge**) to measure the **source charge's** electric field.
    - The **test charge** is an infinitely small, **positive** charge. It is a mathematical creation… they don't really exist.
    - Since it is infinitely small, it has a super small electrical field of its own, so we will treat it as having no electric field. This is good, since we don't have to be concerned with its electric field affecting the results.
    - It is usually given the symbol q, just like any other charge.

Since a **test charge** is ***always*** **positive...**

- if we see the **test charge** move **towards** the **source charge**, we know that the **source charge** must be **negative**
- if the **test charge** moves **away** from the **source charge**, then the **source charge** must be **positive**.

Example 1: You have a **steel ball** that has an unknown charge on it (this is your **source charge**). When you place a **test charge** to the right of the **source charge**, you see the **test charge** move away, to the right. **Determine** if the **steel ball** is positive or negative.

Since the **test charge** is positive (like always), it would only be repelled by another positive object. The **source charge** (the **steel ball**) must therefore be positive.

Measuring Electric Fields

According to Coulomb's Law, the force exerted on the **test charge** must be directly proportional to its own charge and the **source charge**...

$$F_e \, \alpha \, q_1 \, q_2$$

where we assume that q_2 is the **test charge**, which we will rename to simply q...

$$F_e \, \alpha \, q_1 \, q$$

If you divide the force by the charge on the **test charge**, you get a new formula.

$$\vec{E} = \frac{F_e}{q}$$

$\vec{E}$ = electric field (N/C)
F = force (N)
q = charge on **test charge** (C)

Warning!
There are two very important things to notice about this formula as it appears on the data sheet.
First, the **arrow** above "E" in the formula shows this is the **vector** measurement of **field**;
Without the arrow it is the **scalar** "**energy**." You ***must*** write the arrow above "E" in this formula, since you are otherwise showing it as energy.
Second, the data sheet does not show "q" as being anything special (like a test charge).
You need to remember that this formula uses the charge of the object testing the field, not making it. More on this idea after the following example.

Example 2: I place a 3.7 C test charge 2.7m to the right of a -7.94C source charge. If there is an attractive force of 3.62e10 N acting on the test charge, **determine** the field strength of the source charge at that location.

We don't need the distance to figure this question out. It is important to know that the test charge is to the right of the other charge, since we need to give a direction.

$$\vec{E} = \frac{F_e}{q} = \frac{3.62e10}{3.7} = 9\,783\,783\,784 = 9.8e9\ \mathrm{N/C} \quad [\text{left}]$$

The field points left because that's the direction the test charge is being pulled. By definition, the direction of an electric field is the direction a ***positive*** test charge is pushed or pulled.

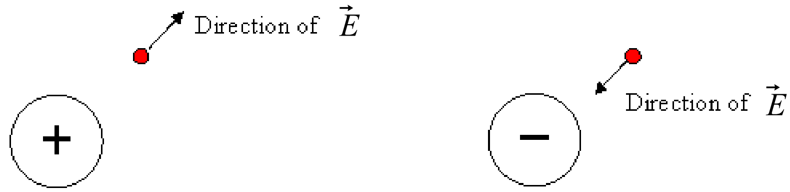


Illustration 2: Direction of electric field near positive and negative charges.

Super Important Note!

One of the most important things to remember when using this formula is which charge is used. Do you use the source charge that is creating the field, or the test charge that is placed nearby to measure the field. The answer, as shown in Example 4, is the test charge. But this is often something that students forget or mix up. There is a way to remember.

Let's keep in mind that you've already studied fields when you learned about gravity in Physics 20. We can look at the parallels between the following two formulas to remember things about each of them.

$g = \frac{F_g}{m}$	$\vec{E} = \frac{F_e}{q}$
g = measurement of the ***gravitational*** field strength F_g = the force acting on the small object m = mass of the small object (like a person), ***not*** the large object (like the earth) *This formula measures the amount of force per unit mass.*	$\vec{E}$ = measurement of the ***electric*** field strength F_e = the force acting on the test charge q = the charge of the test charge, ***not*** the source charge making the electric field *This formula measures the amount of force per unit charge.*

When you use the formula $F_g = mg$ you (usually) use a small mass that is sitting on or near a planet that is creating the gravitational field, not the mass of the planet. The charge in the formula $\vec{E} = \frac{F_e}{q'}$ is the small test charge sitting near the bigger sourcecharge that is making the electric field.

The electric field around a source charge will be different at different locations around the charge.

- Further away from the charge, the magnitude of the force will decrease. We know this from Coulomb's law...

$$F_e \alpha \frac{1}{r^2}$$

- The direction will also be different...

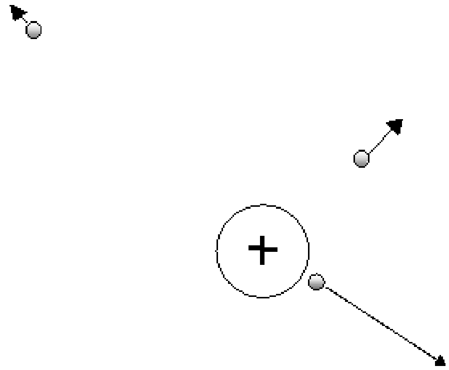


Illustration 3: Different directions and magnitudes of electric field strength at different positions around a charge.

Example 3: A force of 2.1 N is exerted on a 9.2e-4 C test charge when it is placed in an electric field created by a 7.5 C charge. If the force is pushing it West, **determine** the electric field at that point.

Notice that the direction of the field is to the West. Since the positive test charge is being pushed to the West, the field must point in th same direction.

$$\vec{E}=\frac{F_e}{q}=\frac{2.1}{9.2\text{e-}4}=2282.608=2.3\text{e}3\ \text{N/C}[\text{West}]$$

Example 4: If a positive test charge of 3.7e-6 C is put in the same place in the electric field as the original test charge in the last example, **determine** the force that will be exerted on it.

$$\vec{E}=\frac{F_e}{q}$$

$$F_e=\vec{E}q=2.3\text{e}3(3.7\text{e-}6)=0.00844565=8.4\text{e-}3\ \text{N}[\text{West}]$$

Example 5: You now place a -4.81e-2 C charge at that spot in the electric field. **Determine** the force acting on this charge.

This time we put a negative charge in the electric field. We just calculate the absolute value to find the magnitude of the force, then reason out that if a positive charge is being pushed to the West, a negative charge will be pushed to the East.

$$\vec{E}=\frac{F_e}{q}$$

$$F_e=\vec{E}q=2.3\text{e}3(4.81\text{e-}2)=109.793=1.1\text{e}2\ \text{N}[\text{East}]$$

There is another way to measure electric field strength based on a combination of the formula we've already got and Coulomb's Law...

$$\vec{E} = \frac{F_e}{q} \qquad F_e = \frac{k q_1 q_2}{r^2}$$

- In the formula we will assume that q_1 is the source charge that is making the field, and q is the test charge.
- Coulomb's Law can now be substituted into the field formula to get…

$$\vec{E} = \frac{F_e}{q} = \frac{\left(\frac{k q_1 q}{r^2}\right)}{q} = \frac{k q_1 q}{r^2}\left(\frac{1}{q}\right) = \frac{k q_1}{r^2}$$

- This gives us our new electric field formula:

$$|\vec{E}| = \frac{k q_1}{r^2}$$

$|\vec{E}|$ = electric field (N/C)
k = Coulomb's Constant
q_1 = source charge making the electric field (C)
r = distance from the charge (m)

- So you will use the **source charge** that is actually producing the field as q_1.
- This is great! Now you don't have to rely on some imaginary thing like a test charge to calculate the field around a source charge!
- We also need to be careful about calculating the absolute value, since we need to make a decision on the direction of the field based on the info in the particular question we are working on.

Super Important Note!

Just as we were able to find a connection between electrostatics and gravity a couple pages back, we can do the same thing with our new formula.

$g = \frac{GM}{r^2}$	$\vec{E} = \frac{kq_1}{r^2}$
g = measurement of the ***gravitational*** field strength	$\vec{E}$ = measurement of the ***electric*** field strength
G = gravitational constant	k = Coulomb's constant
M = mass of body producing gravitational field	q_1 = charge of source charge producing electic field
r = distance from centre of body	r = distance from centre of body

Example 6: A tiny metal ball has a charge of –3.0e-6 C. **Determine** the magnitude and direction of the electric field it produces at a point, **P**, 30cm away.

$$\vec{E}=\frac{kq_1}{r^2}=\frac{8.99e9(3.0e\text{-}6)}{0.30^2}=299\,666.667=3.0e5\ N/C$$

Warning!
Get used to names for a particular spot like "P", since sometimes we may want to relate what you're doing in a question to several spots, like "P", "D", and "A".

- Remember the electric field is always defined as being in the direction that a **positive** test charge would move.
    - Since the source charge producing this field is **negative**, a **positive** charge would be attracted towards it.
    - **This field points *towards* the metal ball**. That's the direction you would state.

Multiple Source Charges Creating Electric Fields

You will run in to problems where several source charges are interfering with each other to make one electric field.

- Simply calculate the individual electric fields, and then add them as vectors, taking into account directions and angles as necessary.
- Handle these questions like a vector problem from Physics 20. All you want to calculate by the end is a resultant.

Example 7: Two negatively charged spheres are arranged as shown in the diagram below. Determine the electric field strength at a point exactly half ways in between.

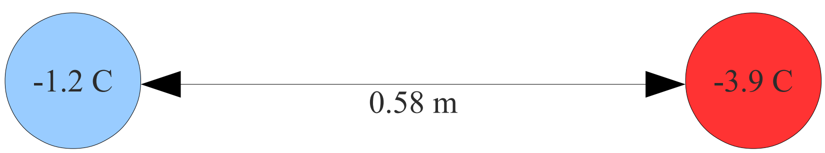


Illustration 4: Charge arrangement for Example 8.

First we figure out the electric field caused by each charge *individually* at the point half ways in between.

$$|\vec{E}_b|=\frac{kq_1}{r^2}=\frac{8.99e9(1.2)}{0.29^2}=1.2827586e11 \qquad |\vec{E}_r|=\frac{kq_1}{r^2}=\frac{8.99e9(3.9)}{0.29^2}=4.1689655e11$$

Now we will take into account the directions and add them as vectors. In both cases the source charge is negative, so the electric field created by both source charges point towards themselves. So, the electric field of the **blue** source charge points to the **left** (we'll say it's **negative),** while the **red** source charge has a field pointing to the **right** (so it will be **positive**).

$$\vec{E}_{total}=\vec{E}_b+\vec{E}_r$$
$$\vec{E}_{total}=-1.2827586e11+4.1689655e11=2.8862069e11=2.9e11\ N/C$$

The electric field is 2.9e11 N/C [right].

Lesson 11: Field Lines

An electric field is a vector, so we can represent it using vector diagrams.

- The electric field will show up as arrows drawn at various points around charged objects.
- These **electric field lines** (sometimes also called ***lines of force***) are drawn below for two simple examples.

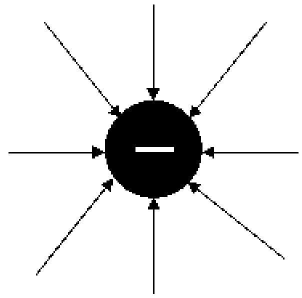


Illustration 1: Field lines around a negative source charge.

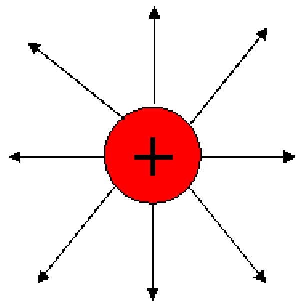


Illustration 2: Field lines around a positive source charge.

Notice that the lines are drawn to show the direction of the force, due to the electric field, as it would act on a **positive** test charge.

- Also, the closer you get to the charge, the closer the lines are to each other. This symbolizes how the electric field gets stronger as you go closer to the source.
- If you pick a spot further out, you'll see that the lines aren't as dense there… so the field is weaker.

If a positive and negative charge are close enough, their field lines can interact.

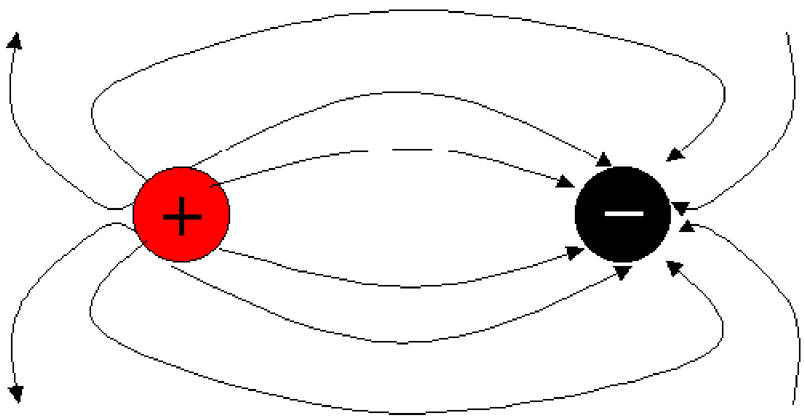


Illustration 3: Two opposite charges showing the interaction of their field lines.

- The arrows go from the positive charge to the negative charge (in exactly the same direction we would expect a positive test charge to move).
- The direction of the field at any point is the tangent drawn to the field line at that point.
- Faraday used this model to explain why these two opposite charges would attract each other.
    - Field lines try to be straight, not curved. If the two charges come closer together, it can be shown mathematically that the field lines overall become straighter on average.

If you have two charges with the same sign, you get a different looking diagram.

- We still follow the rule that the field lines show the direction a positive test charge would move.
- For this example we will assume that we are looking at the field created by two positive source charges near each other.
  - At first, the test charge overwhelmingly just wants to get away from the charge it's closest to.
  - By the time it gets a little distance away, the field of the other object starts to affect it as well, so it begins to curve away from there also.
- Faraday used this to explain why two like charges repel... again, the field lines are trying to straighten out.

Another important example of field lines comes from the need to sometimes have a constant, **uniform** electric field.

- As you can see in the previous examples, the fields have very different field strengths at different points… they're irregular.
  - That's because they are made up of only two charges, so the field lines wrap around a lot.
- If we could get a whole bunch of charges lined up evenly then we could get a more uniform electric field.
  - It is possible to set this up using two plates that are parallel to each other with opposite charges built up on them, as shown in Illustration 4.
  - This is how physicists set up their lab equipment when a uniform field is needed.
- The field lines are very uniform all the way, except for a slight curvature near the ends.
  - We often ignore this slight curvature, since it is very small as long as the plates have a big surface area and are close together. We just make certain not to do any experiments near the ends.
  - The other thing we must be careful about when using parallel plates is that they can arc. Since we can have quite a bit of charge on these two plates, electrical sparks can jump between them, screwing up any experiment that we might be doing.

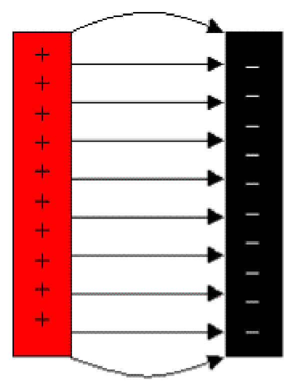


Illustration 4: Parallel Plates with a uniform electric field.

Homework

p.569 #1, 2

Lesson 14: Magnetism History

The history of magnetism begins with the ancient Greeks in an area known as **Magnesia**.

- According to legend, a shepherd (some say he was named **Magnes**) noticed that the nails of his shoes and metal tip of his staff were stuck to a black rock he was standing on.
  - The rock had magnetite in it, a naturally occurring iron ore with magnetic properties.
- For a long time magnets were thought to be somehow magical, and were treated as a novelty (they weren't used for anything serious).

Eventually it was discovered that a tiny sliver of this magnetic rock floating on the surface of water will spin on its own until one **pole** (end) of the magnet is pointing toward the north. The same pole always ended up pointing north.

- The pole which points north is called the north pole; the other pole that points south is called the south pole.
  - All magnets have a north and a south pole, no matter what shape they might have been bent into, or even if you break it apart into pieces.
  - The magnetic field is the strongest at these poles.
- It is not known for sure when this was discovered, but the Chinese were making use of simple compasses by the eleventh century.

As magnets are brought near one another, they exert a force on each other.

- The force can be either attractive or repulsive and can be felt even when the magnets don't touch (force at a distance).
- This leads us to the **Law of Magnetism** which says "**Like poles repel and unlike poles attract**."
- This is like the force between electric charges., but not exactly the same. ***Electrical charges and magnetic poles are different.***

Many people (wrongly) assume that magnets can stick to any metal.

- In fact only a few elements on the periodic table actually have any magnetic properties strong enough to be worth mentioning.
- These elements are known as a group as **ferromagnetic** elements. The name comes from the Latin name for iron... ferrum. The ferromagnetic elements are:
  1. Iron
  2. Cobalt
  3. Nickel
  4. Gadolinium

Did you know?

Cows, not the brightest of creatures, will accidentally eat things like nails and staples while grazing. To prevent these nasty objects from passing all the way through the cow (especially causing damage near the, ahem, *end* of the cow), farmers will feed a cow magnet to a calf to trap the metal. By catching the iron, it is stopped from moving on to areas where it could get lodged and hurt the cow.

As time passed, more and more people tried to explain magnetism.

- William Gilbert (see Lesson 6), wrote a book called De Magnete on the subject.
  - He was able to disprove some old superstitions about magnets, while at the same time presenting his own scientific ideas.
  - He even proposed the idea of an "**orb of virtue**" surrounding every magnet... basically he was describing a **magnetic field**.

Homework

p.592 #1-3, 7

Lesson 15: Magnetic Fields

Did you know?
There are some theories in modern physics that indicate that it should be possible (even though it's never been done) to isolate a north pole from a south pole. The ***di***poles would become ***mono***poles.

We can imagine a magnetic field surrounding a magnet in much the same way that we did for electrical charges.

- One of the biggest differences is that **electrical charges can be isolated from each other** (a negative charge can be sitting all alone), while **magnetic poles must come in pairs** (north and south).
    - So when you draw diagrams of magnetic fields, they will more closely resemble the kinds of diagrams we did with multiple electric charges and parallel plates.
- We will continue to use the concept of "field" to explain how one magnet can exert a force on another magnet by an interaction between magnetic fields.
    - This is action at a distance, like gravity and electric charges.

At this point it would be valuable to compare the three kinds of fields we have examined in Physics 20 and 30.

- Since they are all fields they all share similarities, but they are not the same.
- You should be able to discuss these similarities and differences.

Magnetic Fields	Gravitational Fields	Electric Fields
Strong field.	Weakest of all fields.	Strong field.
Only calculated in Physics 30 in relation to forces acting on something.	Calculated using an inverse square law (*Newton's Universal Law of Gravitation*).	Calculated using an inverse square law (*Coulomb's Law*).
Cause attraction or repulsion.	Cause only attraction.	Cause attraction or repulsion.
Directly related to the magnet involved.	Directly related to the masses involved.	Directly related to the charges involved.
Individual poles can never be separate from each other.	Individual masses are separate from each other.	Individual charges are separate from each other.

Magnetic field strength uses the symbol **B** in formulas, and is measured in **Teslas** (**T**).

- Some examples of magnetic field strength are...
    - Earth's = 5×10^{-5} T
    - Small Fridge Magnet = 0.01 T
    - Magnet in school lab = 2 T
    - Very strong lab magnet = 10 T
    - Surface of Neutron Star = 10^8 T
- The magnitude is defined in terms of the torque ("twisting force") exerted on a compass needle when it makes a certain angle with the magnetic field.
- We will use this vague definition for now, but a more precise definition will develop when we start looking at the math behind this stuff.
- The terms "**magnetic flux density**" and "**magnetic induction**" are sometimes used for **B**, rather than the term "**magnetic field**."

To draw magnetic field lines, follow these rules:

1. We imagine that we have a compass where the north pole is an arrow head. The field lines point in the direction the compass would point if placed in the field (we use it in a way similar to the use of test charges for electric fields). This means that the magnetic field points **away from north** and **towards south**.
2. The density of the field lines (how close we draw them to each other) is related to the strength of the magnetic field.
3. At any point, the direction of the magnetic field is along a tangent line drawn on the magnetic field line (if it is curved).

When you are drawing the magnetic field, you can label it as B , especially if there are other things being shown in the diagram.

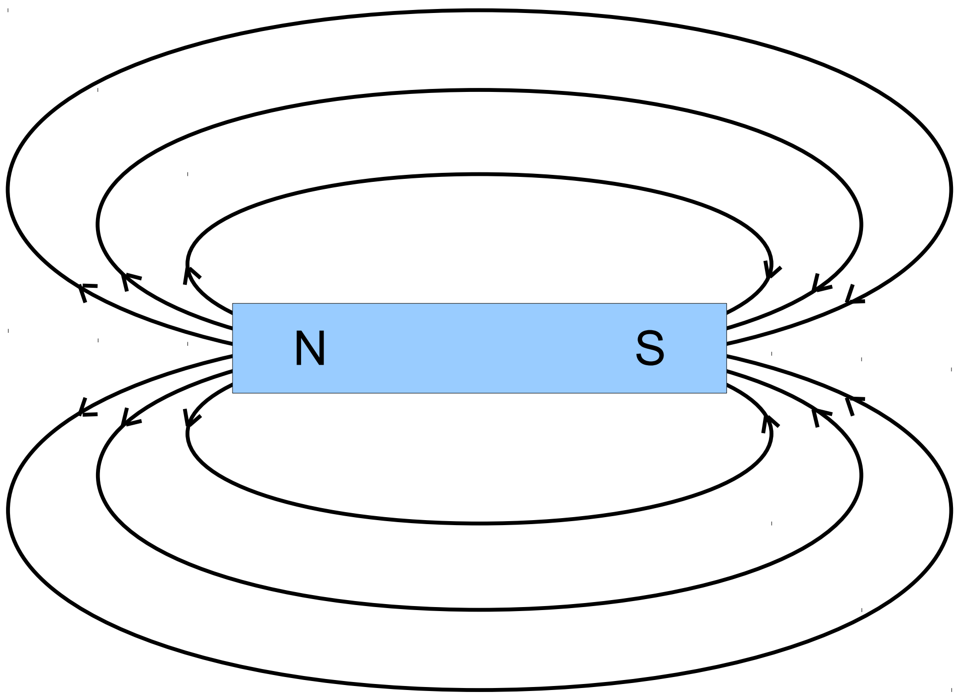


Illustration 1: Magnetic field around a magnet.

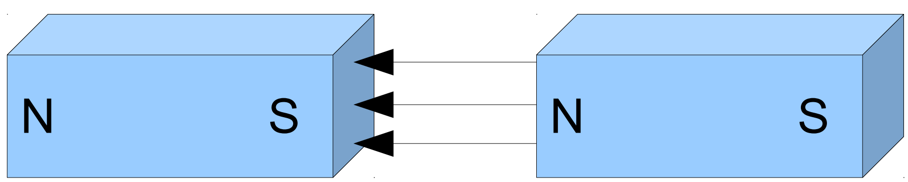


Illustration 2: Magnetic field between two magnets. Note: there would be a slight curvature of the magnetic field near the top and bottom.

William Gilbert was the first person to truly show that the Earth behaved like a giant magnet.

- Before this time, it was believed that there was something like a magnet sitting up in space up near the north and south poles of the Earth.
- Gilbert's experiments with a magnetic sphere showed him that the Earth itself must have a magnetic field of its own to have the effect on compasses that he observed.
- The earth's magnetic poles are shown in Illustration 3.
    - First, notice that the poles are reversed when you compare **geographic** and **magnetic** poles.
        - At the **north geographic** pole where Santa lives you will find the Earth’s **south magnetic** pole.
- Remember how we defined the north end of a magnet... we said it points towards **geographic north** on the earth.
    - But that must mean that there is a **south magnetic** pole up there, since south attracts north.

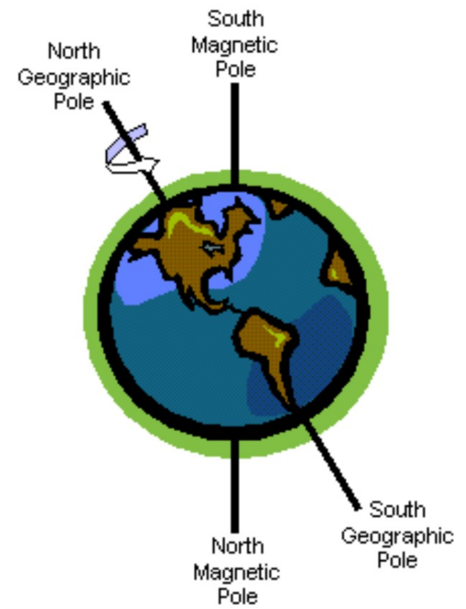


Illustration 3: Earth's magnetic and geographic poles.

Also notice that the **magnetic** poles do not line up with the **geographic** poles.

- The **geographic** poles are based on the axis that the earth spins around.
- The **magnetic** poles are based on where the poles of earth’s “magnet” are found.
- The magnetic south pole is in northern Canada, about 1500 km from the geographic north pole.
    - This must be taken into account when using a compass.
    - The angular difference between **magnetic** south and true **geographical** north is called the **magnetic declination**. In Canada it’s about 0° to 20°, depending on location.

When asked to draw the magnetic field of the Earth, imagine what a peeled mandarin orange looks like.

- The vertical lines running up and down along the orange are field lines.
- Near the top and bottom of the orange are the holes that you pull the pulp out of. This is where the north and south poles are located.
    - The Earth has these magnetic “holes” which allow charged particles from the Sun to enter our atmosphere, causing the Aurora Borealis (northern hemisphere) and Aurora Australis (southern hemisphere).

Did you know?

Earth's magnetic field is actually weakening and moving. Don't worry, though. Nothing like stuff in the movie “The Core” is going to happen. Earth's magnetic field has weakened, disappeared, and reversed hundreds of times in the history of the planet. Also, the movement of the poles is not so important anymore, since the use of GPS is becoming much more common. If it's movement continues, the south magnetic pole will be in northern Russia

Homework

p592 #10

Lesson 16: Domain Theory

This lesson is a bit iffy. Because the most modern theories predict the existence of monopoles, domain theory itself may eventually prove to be wrong. At present, it still serves as a good model of the behavior of magnets, especially at a high school level. In this way it is sort of like using the Bohr model of the atom in Chem; we know it isn't perfect, but it serves its purpose in our studies.

As mentioned in the last lesson, there are theories that we should be able to separate magnetic poles from each other, although no one has ever been able to actually do it.

- Instead, if a bar magnet is cut in half you get two *new* magnets, each with its own north and south poles.
- This means that any current theory of magnetism should be able to explain the **dipolar** nature of magnets.

To do this, picture an atom as looking something like Rutherford's Planetary model, the one where electrons orbit the nucleus like little tiny planets around a sun.

- You can imagine the electrons as spinning around the nucleus, while at the same time spinning around on their own axis (just like the Earth as it goes around the Sun).
- For reasons that are not entirely understood, this **induces** a mini magnetic field all of its own.
    - Enough of these individual microscopic magnetic fields add up to act as a **domain**.
    - Each domain acts as a miniature magnet, with its own north and south poles.

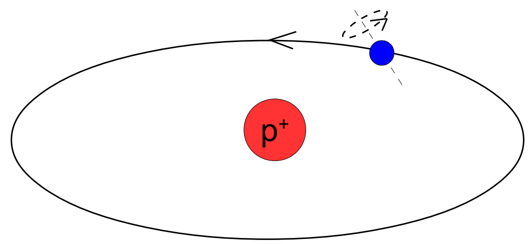


Illustration 1: Picture the electron as orbiting the nucleus, with the electron spinning on its own axis.

In most materials, these domains are random, pointing in all sorts of directions.

- Overall, randomly, these domains tend to cancel each other out.
- This explains why almost all materials are not magnets.
    - The domains start off random, and can ***never*** be aligned.

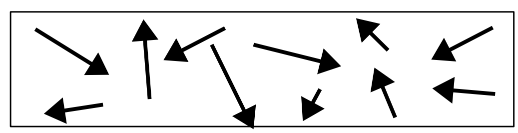


Illustration 2: Random domains result in no overall magentic field.

In ferromagnetic materials the domains *can* align.

- This does not mean that all ferromagnetic materials have to be magnetic. The domains might be random.
    - The difference for ferromagnetic materials is that they can align their domains.
        - This can be done by doing things like placing an existing magnet on the ferromagnetic material you want to align.

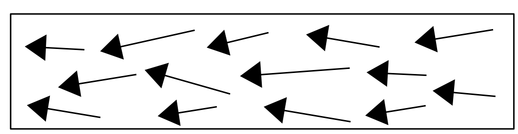


Illustration 3: Domains will mostly line up in magnets.

Warning!
Always remember that all matter contains electrons, so all matter has domains. If this is true, then why can't everything be a magnetic? The reason is that only ferromagnetic materials can rearrange their domains to line up. The exact reason for this property of ferromagnetic materials is not entirely understood.

The question comes up as to whether or not doing something to a piece of iron will make it a **permanent** or a **temporary** magnet.

- This depends mostly on how the metal is forged.
- If the domains are pretty much locked in place, then a **permanent magnet** will be formed. If this is done with iron, it is called **hard iron**.
- If the domains can be moved around easily, then **temporary magnets** will be formed. This would be **soft iron**.
  - Soft iron is useful if you want to make something like an electromagnet to pick up cars. It allows the magnetic field to be "switched" off and on. We will look at electromagnets in more detail later.

The terms "**hard**" and "**soft**" iron only refer to its magnetic properties. Neither of the two irons is actually physically harder or softer than the other.

Domain theory also gives us an easy way to look at demagnetizing an existing magnet.

- If you drop a magnet on the floor or strike it with a hammer, you are basically adding energy to the atoms of magnet.
  - Some of this extra energy will cause the atoms (and the electrons) to jiggle around more randomly.
  - This will screw up the alignment of the domains.
- Heating a magnet has pretty much the same effect, since raising the temperature will also increase the random motion of the electrons and domains.
  - Above a certain temperature, known as the **Curie temperature** (1043 K for iron), a magnet cannot be made at all.

Remember that "**K**" stands for "degrees **Kelvin**." To convert it to degrees Celsius, just subtract about 273°.

Homework

p592 #11, 12

Lesson 17: Linking Electricity to Magnetism

As you just learned in the previous lesson, the magnetic field of a magnet basically comes from the spinning of electrons in atoms.

- This is a relatively recent theory, and certainly did not help scientists hundreds of years ago when they were first trying to figure out why magnets were magnets.
- One of the few hints they had was that electric and magnetic fields did seem to be quite similar.

The breakthrough came in 1820 when Hans Christian Oersted performed a series of public experiments that showed how electric current could affect magnets.

- At first, things didn't work too well in the demo since the wire was being held ***parallel*** to the compass that was being used.
- More by accident than anything, the wire was eventually held ***perpendicular*** to the wire.
  - This resulted in the compass spinning to point in a different direction.
  - The conclusion was that the current flowing through the wire caused a magnetic field to be formed around the wire.
  - We will say that the current flowing through the wire **induced** a magnetic field.

> The term **"induced"** just emphasizes that the current carrying wire is not a magnet itself, but that it causes an effect that us the same as a magnet.

To keep track of the direction of the magnetic field around the wire, we use a series of rules based on holding your hand in certain positions.

- In all of these rules we will be using different parts of your hand since they are perpendicular to each other, just like the results Oersted had in his experiments.
- No matter which rule you are using first make the choice of which hand you are supposed to be using:

  Electrons, electron current flow, or anything negative → left hand
  Protons, conventional current flow, or anything positive → right hand

- We will assume that the current flowing through the wire is "electron flow" unless we have a good reason to think otherwise.
  - In this model, the flow of charges through the wire is made up of electrons.

When we draw diagrams for the following rules, we often do it using simple arrows as symbols of the directions involved.

- Since some of the directions will sometimes be in and out of the page, we will use two special symbols.
  - The first is a circle with a **dot.** It is supposed to look like the tip of an arrow coming out towards you. It shows a vector coming **out** of the page.
  - The second is a circle with an **X.** It is supposed to look like the feathers of an arrow going away from you. It shows a vector going **into** the page.

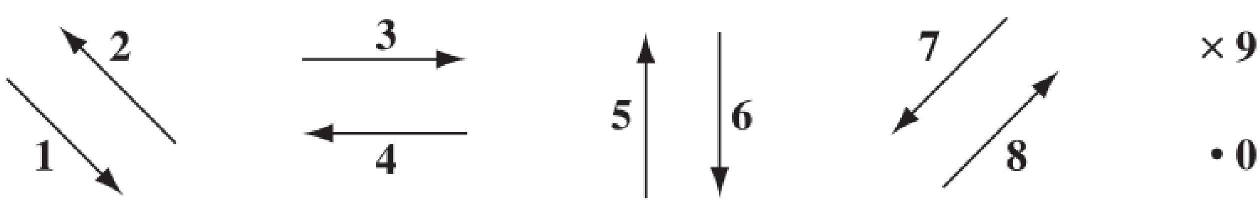


Illustration 1: Examples of directions as used for numerical response questions.

Warning!
Avoid the temptation to use words to describe directions in questions involving magnetic fields. One person might say "up" to mean "up to the top of the page," while another person means "up out of the page."

First Hand Rule

In the textbook you will sometimes see the **first hand rule** called the **wire grasp rule**.

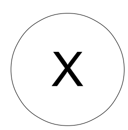
The first hand rule applies to situations involving a straight current carrying wire.

- Imagine grabbing the wire with your left hand (assuming it is electron flow).
  - Your **thumb** must point in the direction the **current** is flowing in the wire.
  - Your **fingers** wrap around the wire in the direction of the **magnetic field**.

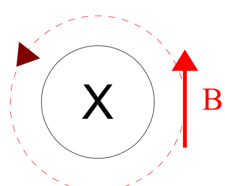
This means that the magnetic field around the wire forms an endless loop all the way around the wire.

- Your fingers are pointing in the direction of the magnetic field, so if you were to place a compass next to the wire it will point in a direction at a tangent to the circle you just drew.

Example 1: A current carrying wire is shown here. Draw a vector that shows the direction of the magnetic field to the right of the wire.



This diagram is showing a wire with the electron flow current going into the page. To picture the solution for this, grab something in your left hand like a pencil. Make sure the pencil is pointing away from you and grab it so that your thumb is also pointing away from you (the direction of the current). Notice how your fingers wrap around the pencil counter-clockwise. Although it wraps all the way around the wire, we only care about what's happening on the right side of the wire, so draw a vector there that is tangential to the circle... it points towards the top of the page.



Second Hand Rule

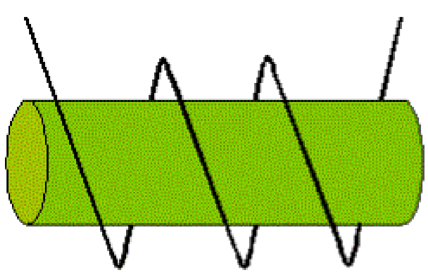


Illustration 2: A solenoid is a coil of wire.

The second hand rule is used when a wire is coiled up, called a solenoid.

- In *Illustration 2* I drew a green tube just to make it easier to see it in 3-D... all you need are the loops of wire.

The magnetic field in a solenoid can be very strong, since each loop strengthens the fields created by all the other loops in a row.

- As a whole, the solenoid will act exactly like a magnet in every way.

We use the second hand rule in situations involving a solenoid (coil of wire).

- Starting at the end of the wire where the current begins, point your **fingers** in the direction of the **current** flowing in the wire.
  - Follow the wire so that you are grasping the "cylinder" with your fingers wrapping around it, still in the direction of the current.
- Your **thumb** points in the direction of the **north end of the solenoid**.

If you place a piece of a ferromagnetic material (like iron) in the solenoid where the green cylinder is, the strength of the magnetic field increases greatly.

- In fact, this can easily make the magnetic field hundreds or even thousands of times stronger!
  - This is due to the domains in the piece of iron aligning with the field created by the current in the wire.
- When a solenoid is "enhanced" using ferromagnetic cores this way it is commonly called an **electromagnet**.
  - The iron used in most electromagnets is soft iron so that it can be turned off and on whenever needed.

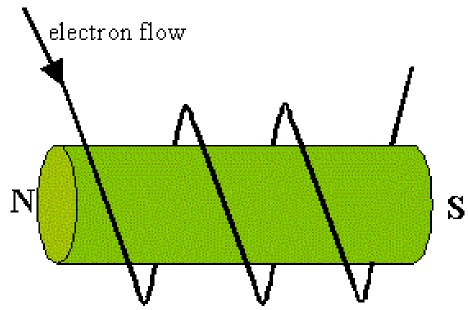


Illustration 3: The current flowing this direction through the wire induces the poles as shown.

Because there is a constant current going through the solenoid wire, a great deal of waste thermal energy is given off.

- In large solenoids and electromagnets there is often a system of cooling coils.
  - This drives the cost up very quickly.
- This is why there is a lot of research into superconductors, materials that don't require electric power flowing through them constantly to maintain the current.

Third Hand Rule

It makes sense that if a current carrying wire induces a magnetic field around it, it should feel a force if it is brought near a separate magnet field.

- To keep the two different magnetic fields straight in our heads, we will refer to the one created by the separate magnets the external magnetic field... it's external to the magnetic field of the wire itself.
- *Illustration 4* shows a current carrying wire running into the page and the external magnetic field that is around it.
  - Don't worry, we haven't magically created monopoles. We're just showing the parts of two magnets that will make a uniform external magnetic field.
  - If we want, we can draw the diagram more simply as shown in *Illustration 5*.

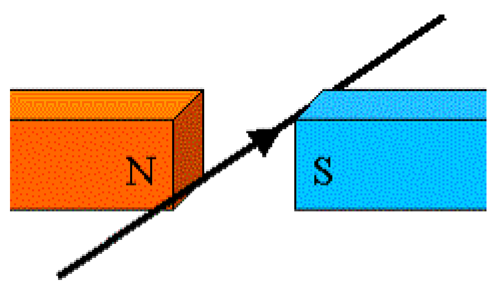


Illustration 4: A current carrying wire in an external magnetic field.

The third hand rule has three parts: the external magnetic field, the charge or wire in the field, and the force exerted on it.

- Your **fingers** point in the direction of **the external magnetic field, from North to South**.
- Your **thumb** points in the **direction the current is flowing through the wire**.
- Your **palm** pushes in the direction of the **force acting on the wire**.

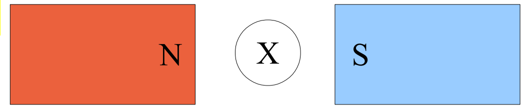


Illustration 5: Simplified diagram of a wire in a magnetic field.

In *Illustration 5* this would mean that the arrow showing the direction of the force acting on the wire would be pointing up to the top of the page. ↑

The magnitude of the force acting on the wire can be calculated using the following formula...

$$F_m = I\,l\,B\sin\theta$$

F_m = force of external magnetic field on wire (N)
I = current flowing through wire (A)
l = length of wire in magnetic field (m)
θ = angle between wire and magnetic field (degrees)

The force is a maximum when the wire and external magnetic field are perpendicular to each other.

- If they are perpendicular you will be taking the sine of 90°, which equals one.
- For any angle less than 90° the force becomes less and less.
- If the wire and external magnetic field are parallel, the force is zero.

The textbook calls the force of the external magnetic field (F_m) the **motor effect force**, since it is the basis of why electric motors work (more on this later).

Example 2: A piece of wire that is 3.45m long is placed in a 1.29T magnetic field at a 67° angle. If the force on it is 1.884 N...

a) **determine** the current in the wire.

$$F_m = I\,l\,B\sin\theta$$

$$I = \frac{F_m}{l\,B\sin\theta}$$

$$I = \frac{1.884}{3.45(1.29)\sin 67}$$

$$I = 0.459881575 = 0.46\,A$$

b) **determine** the amount of charge that flows through the wire in 7.10 s.

This is based on the formula for electric current...

$I = \frac{q}{t}$ where I = current (A) , q = charge (C) , and t = time (s)

$$q = I\,t$$

$$q = 0.459881575(7.10)$$

$$q = 3.265159185 = 3.3\,C$$

The same third hand rule can be applied if you are dealing with individual charges moving through an external magnetic field.

- Simply replace the direction of the current flowing through the wire with the direction of the charge moving through the external magnetic field.
    - Remember, use your left hand for negative charges and your right hand for positive charges.

The formula looks a little different, since you have to adjust it for charges instead of wires...

$$F_m = qvB\sin\theta$$

F_m = force of external magnetic field on charge (N)
q = charge (C)
v = velocity of charge (m/s)
θ = angle between charge and magnetic field (degrees)

Example 3: If an alpha particle moves at 1.22e4 m/s through a 23 T perpendicular magnetic field, **determine** the force it will experience.

The particle enters at 90°, and sin90° = 1, so we can ignore that part of the formula.

$$F_m = qvB$$
$$F_m = 3.20\text{e-}19(1.22\text{e}4)(23)$$
$$F_m = 8.9792\text{e-}14 = 9.0\text{e-}14\ N$$

Homework

p599 #1,2
p600 #1,2
p601 #5,8,9
p603 #1
p605 #1